DEVELOPMENT OF BLOWOUT FIRE SUPPRESSION SYSTEM TECHNOLOGY

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The work described herein is an experimental investigation to determine if advanced technologies could be applied to the suppression of blowout fires. Work is continuing.

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Progress Report

Development of Blowout Fire Suppression System Technology

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SUMMARY

The Center for Fire Research is conducting reduced scale experiments directed toward the development of blowout fire suppression technology. Two concepts are being investigated; the first consists of water sprays directed toward a vertical diffusion gas flame; and the second consists of injection of a suppression agent in the gas flow stream, upstream from a diffusion burner. Previous calculations estimated that a mass flow ratio of water to hydrocarbon of 10 was necessary to obtain extinguishment (through cooling). In the experiments with the exterior application of water sprays, extinguishment was achieved at ratios of about 7. The direction and shape of water spray patterns were found to be important in achieving extinguishment with this ratio. In the tests where water was injected into a propane gas flow stream, extinguishment was achieved at a mass flow ratio of 2. Based on these preliminary favorable results, experimental work is proceeding to further develop both concepts.

1. INTRODUCTION

In a previous report by O'Neill [1], it was determined that blowout fire suppression technology should address two distinctly different types of blowout fires which can occur on a platform. The first results from a blowout through the drill pipe. Such a fire would occur above the drilling deck. The second results from a blowout resulting at any number of locations in the drilling fluid (mud) return piping. A fire resulting from this type of blowout could occur at any number of locations; for instance, at the top of the marine riser, in the choke piping assembly, or in the mud return line.

Therefore, two fire suppression system concepts are being examined. The first concept, envisioned in full-scale in figure 1, is being investigated through a series of experiments in which water spray nozzle systems are directed against a vertical diffusion flame. The purposes of the experiments are to 1) quantify mass flow ratios necessary to accomplish extinguishment, and 2) to develop, at least qualitatively, information concerning the sensitivity of the spray distribution and spray nozzle orientations to extinguishing performance. The second concept, which addresses the latter blowout fire scenario, is being initially investigated through experiments in which water is injected into a propane gas pipe upstream from a burner. This concept suggests that by mixing the suppression agent in the fuel flow stream the blowout fire can be extinguished regardless of location (see figure 2). Again, as in the series of tests with the spray nozzles, the primary objective in this initial phase is to determine the mass flow ratios of water to gas necessary to extinguish the fire.

2. SUPPRESSION AGENT

In both experimental efforts the primary suppression agent being investigated is water. Water is considered the most desirable suppression agent for this technology since it would be limitless as a supply for the suppression system. Considering the long duration of blowout incidents, a virtual limitless supply can be considered key to the feasibility of such technology.

The use of water for fire extinguishment has been known to man for probably as long as fire itself. However, due to the complex physico-chemical mechanisms involved, quantitative understanding of the process is still incomplete. Direct cooling of the fuel, dilution and cooling of the pyrolysis products, oxygen concentration reduction and other direct chemical effects may all be taking place simultaneously. There are no valid models of the phenomena, and there is little research data available on the subject.

In large scale flares used in the chemical industry, water in the form of steam is often mixed with the effluent before burning. The purpose of this process is to reduce the soot produced in the combustion process for environmental considerations. Since most of the radiation in a diffusion flame arises from soot emission, reduction of the soot will bring about a reduction in the radiation. (It is well established that other diluents can also reduce radiation). The rationale for using liquid water (besides its availability and the lack of any preparation requirement, as is necessary for steam), is that liquid water is far superior, from a thermodynamic viewpoint, to steam. One not only obtains the sensible heat required to raise the water temperature from ambient to the boiling point, but also the very large latent heat of vaporization is available for cooling.

The principal difficulty of using liquid water concerns the problem of getting the liquid into the flame or mixed into the gases prior to the combustion zone; diluents used in previous radiation reduction studies were generally well-mixed with the fuel. It is expected that the effectiveness of these fire suppression techniques will be a strong function of how efficiently the water is injected or sprayed into the flame gases. For the experiments reported here, an injection of liquid spray or fog was chosen in a convenient geometric arrangement in order to establish some base-line criteria of effectiveness. Other methods of injection in larger scale will be compared with this somewhat idealized configuration at a later point in the program.

In this initial series of experiments, the results demonstrate encouragement regarding the use of water sprays for fires characteristic of oil well blowouts. The following sections present the results of the work completed to date in both the spray nozzle studies and the water injection studies. These results will serve as a basis for further scaling studies and improved modeling capabilities in the subsequent phases of the study.

3. EXPERIMENTAL - EXTERIOR WATER SPRAY ENTRAINMENT SYSTEM

Reduced scale tests are being conducted at the NBS Annex in a former NIKE missile pit as depicted in figure 3. This facility is particularly useful since it permits repeatable tests in a partially open, ventilated environment, and the effects of variable wind conditions from one day to another can be minimized*.

The burner, which simulates the fire plume, consists of a vertical 26 mm (1 in) pipe with orifices of varying diameters. The methane burner is supplied by a bank of cylinders through a series of regulators, valves and a flow meter. Commercially available water spray nozzles were selected based on flow characteristics and spray pattern specifications from the manufacturers. The water supply to the nozzles is metered. In the previous report [1], a ratio of 10 (water to gas) was estimated as necessary for extinguishment. The initial flow rates for water and gas were established close to this ratio. For a given nozzle configuration, these rates were modified following analysis of the results of previous tests. Wide view total heat flux meters as shown in figure 3 were arranged to measure radiative heat output. Thermocouples were placed high in the flame to record plume temperatures during the tests.

The nozzle positions investigated in the project are shown in figures 4 and 5. Nozzles of different orifice sizes but of the same spray pattern were used in each of these nozzle positions. For purposes of identification, each of the six nozzles were coded A through F (thus far in the project). For example, nozzle configuration C-1 refers to nozzle C in nozzle position 1 as shown in figure 4.

*It is expected that the effects of wind must be taken into account in later stages of the experimental work. However, at this early stage it is more important to examine the performance of various water spray systems against a reasonably uniform flame envelope.

3.1 Results - Exterior Water Spray Entrainment System

In a preliminary test a single "A" nozzle was placed in nozzle position 1 (i.e. A-1). The spray had minimal effect on the flame at a heat release rate of ($\dot{Q}$) = 590 KW. The flame merely projected away from the spray and could not be extinguished despite an increase in water flow rate over the fuel flow rate approaching a ratio of 20:1. Following this preliminary test, two nozzles were positioned such that the water sprays converged in the base of the plume as shown in NP-1. This arrangement was very effective in extinguishing the test fires. Over a range of gas flow rates from $\dot{Q}$ = 590 KW to 2800 KW, extinguishment was achieved at ratios ranging from 6.4 to 8.6. The two nozzles were then rearranged as shown in NP-3 and extinguishment was also achieved, but at a less efficient ratio of 9.5.

As the nozzle positions were varied as illustrated in NP-2, and in NP-4 through NP-6 (figures 4 and 5), extinguishment was not be achieved. It is important, however, to note that those nozzle configurations had a distinct effect on reducing radiative heat and plume temperatures. These data are still being analyzed and will be discussed in detail in the full report.

From the tests conducted thus far, NP-1 (with various nozzle sizes) was repeatedly more effective than the other nozzle configurations, and it did so at mass flow ratios ($\dot{m}_{H_2O}/\dot{m}_{CH_4}$) of less than 10 as previously estimated. Figure 6 indicates the results of tests where extinguishment was accomplished. The results are for three different nozzle sizes, all with similar spray patterns, and arranged in the NP-1 position. The data indicated that the higher the fuel flow rate ($\dot{Q}$), the more efficiently extinguishment was accomplished (lower $\dot{m}_{H_2O}/\dot{m}_{CH_4}$). However, as the fuel flow rates were increased, so were the exit velocities. Therefore, it was surmised that the suppression systems became more efficient as the fuel exit velocities increased. This was verified when tests were conducted with a smaller orifice burner in which fuel flow rates were the same as several previous tests. In these comparative tests where flow was kept constant, and the velocities were increased, the ratios of water to gas remained the same or were improved over the tests conducted at lower velocities.

This is important in considering the extension of these results to larger scale fires. In full-scale blowout incidents not only are the flow rates higher than laboratory tests, but the exit velocities are higher as well, approaching sonic speed (about 1600 ft/sec for methane)[2].

At this stage it appears that the NP-1 arrangement is effective in extinguishing these fires through a combination of flame separation and plume cooling. The converging sprays from opposing nozzles over the burner outlet collide, and water droplets are readily carried up into the flame plume. In the next several weeks, the sensitivity of where this convergence occurs in the flame envelope will be closely examined. This geometric parameter must be carefully considered before finalizing plans for extension of this work to larger scale fires during the next fiscal year.

4. EXPERIMENTAL - WATER INJECTION SYSTEM

The experimental design for the laboratory scaled injection studies consisted of a spray nozzle located concentrically within a cylindrical pipe which supplied the gaseous fuel for the diffusion flame simulation. This design permitted most if not all of the water to reach, or otherwise be entrained into, the combustion region. The fuel pipe was standard 26 mm ID (1") wrought iron pipe. The nozzle, contained in an 18.3 mm OD fitting, was a standard residential oil burner nozzle (Delavan 2.50-30°B), solid cone type with a nominal 30° spray angle, which protruded about 13 mm above the end of the fuel pipe. The gas, commercial propane, flowed through the annulus formed by the outside pipe and the inside nozzle fitting in a diffusion mode. Gas and water flows were monitored using standard flowmeters. Radiation measurements were made with a total heat-flux sensor in the manner described in reference [3]. The primary measurement consisted of the total radiative power output; that is, the fraction of the nominal heat-release of the flame which is radiated away. It was intended to observe the reduction in this parameter as a function of water flow-rate.

4.1 Results - Water Injection System

Propane gas mass flow rates for the experiments were between 0.4 and 2.8 g/s, corresponding to fire sizes of between 20 and 130 kW, or a flame height of about 0.5 to 2 m (see ref. [3]). The Froude number for these flows, $U_o/\sqrt{gD}$, ranged from about 2 to 13 using the equivalent diameter, D, based on area of the annulus (U_o being the source velocity). This number is an important scaling parameter for these studies -- as a measure of the relative amount of momentum contained in the gas stream. In future scaling studies, the momentum of the liquid spray will be compared to the stream momentum, regarding mixing, entrainment, flame stabilization and blowoff.

Figure 7 presents the radiative fraction, designated $\dot{Q}_{RO}$, (the subscript zero, indicating measurements without liquid spray), plotted against Froude number. Other measurements for propane C_3H_8 in the literature are also shown on the figure. The annular results obtained so far fall between Markstein's [4] nozzle results and tube results from reference [3]. The lower radiation levels from the nozzle flames are thought to occur due to better mixing of the gas jet with the surrounding air at the exit of the nozzle. Figure 7 is a good overall picture of the behavior of the radiation from diffusion flames. For moderate Froude numbers the radiative fraction remains fairly constant with flow-rate, and is independent of diameter. With increasing gas flow from a fixed pipe, the radiation will begin to decrease as the flame begins to lift off the end of the pipe until, at some sufficiently large flow rate, the flame can no longer be sustained and blowoff results. Unfortunately, this decreasing radiation and blowoff behavior seen on figure 7 at Froude numbers of a few hundred will be a function of pipe size. Satisfactory scaling of these effects needs to be established.

Figure 8 presents the reduced radiation, $\dot{Q}_R/\dot{Q}_{RO}$, plotted against the ratio of water mass flow-rate to gas mass flow-rate for three different water flow-rates. The data start at $\dot{Q}_R/\dot{Q}_{RO} = 1$ for no water addition and begin to fall as water flow is increased for a given fire size. How rapidly the radiation is reduced is a strong function of the water flow-rate level. Note these data were obtained using a fixed water flow-rate, while the gas flow-rate was varied. The characteristics of the spray, including its momentum and droplet particle size distribution, is expected to vary greatly with the hydraulic pressure driving the nozzle flow. For the range of liquid flow-rates shown, pressure varied with flow-rate squared. Hence, keeping the water flow-rate constant should keep the nozzle characteristics constant.

The lines shown on figure 8 are least squares fit of the data in exponential form. The calculation yields:

$$\dot{Q}_R/\dot{Q}_{RO} = 1 - 0.565 \exp\left[- K\left(\dot{m}_{H_2O}\right) \cdot \left(\frac{\dot{m}_{H_2O}}{\dot{m}_{C_3H_8}}\right)^{-1}\right]$$

where $K\left(\dot{m}_{H_2O}\right)$ as expected, is a very strong function of $\dot{m}_{H_2O}$. Note, as the water-to-gas ratio gets large, the radiation approaches 1 - 0.565 (i.e., 0.435) in the limit for all three sets of data. This is approximately the same order of reduction measured by Gupta [6] using argon and steam premixed into the fuel.

Shown on figure 8 are vertical lines corresponding to a flame blowoff condition. (For the lowest water flow-rate (1.13), the corresponding vertical line would be at $\dot{m}_{H_2O}/\dot{m}_{C_3H_8} \approx 7$.) As the water flow is increased, or in this case, fuel flow decreased, the radiation signal levels off (1 - .565), and does not fall further with increased water flow (similar behavior can be observed in the Gupta [6] data). Instead, the flame begins to be lifted off the end of the pipe and, with further water flow, the flame cannot be sustained. Figure 9 notes this behavior, where the critical mass ratio $\dot{m}_{H_2O}/\dot{m}_{C_3H_8}$ for blowoff is plotted against $\dot{m}_{H_2O}$. Although figure 9 is for a single nozzle with gas and water flow-rates within the range indicated, the characteristic behavior may be more general. Blowoff, like certain other instabilities, is an ill-defined quantity in that these flames are effectively lifted off and sometimes 'exist' as a small ball of pale pinkish-yellow luminosity high above the burner exit at significantly lower water flow-rates than those reported here for blowoff. What is general about figure 9 is the very strong dependence upon water flow-rate (and presumably on the spray characteristics of the nozzle, as seen previously in the radiation results). The asymptotic trend at higher water flow-rates indicates that a ratio of $\dot{m}_{H_2O}/\dot{m}_{C_3H_8}$ equal to about 2 would be sufficient to extinguish the flame.

5. CONCLUSIONS

1. The exterior application of water sprays into the flame envelope from a vertical methane diffusion burner has accomplished extinguishment at mass flow ratios of about 7 (water to gas flow). If the ratio can be extended to full-scale blowout fire incidents, the water flows necessary to accomplish extinguishment are well within water pumping capabilities now commonly provided on platforms and rigs. However, the sensitivity of the convergence of the spray patterns in the flame plume must be further explored.

2. The feasibility of using liquid sprays injected into the gas stream in reasonable quantities for diffusion flame suppression has been demonstrated in a laboratory scale concentric nozzle-burner configuration. Radiation reduction levels of about 57 percent were attained with a water-to-fuel mass ratio of about 1; thereafter, no further reduction was attainable with increased water flow until flame blowoff occurred at ratios near 2. The reduction of fire intensity reflected in radiation measured here are of the same order determined by others using completely premixed diluent systems, and illustrates the tremendous practical potential of liquid sprays.

3. In order to scale these results to larger systems and other nozzle-burner configurations, further study will be necessary. Scaling studies are critical to the successful translation of the present results to actual use in oil well (or gas-well) blowout fires. Specifically, the strong dependence of water flow-rate on effectiveness noted here must be clarified. Determining droplet particle size distribution and resulting spray momentum, fuel jet momentum, entrainment and mixing of the two-phase flow will obviously all be involved.

6. REFERENCES

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[2] Hawkins, M., et al., "Methods for Determining Vented Volumes During Gas Well Blowouts", Coastal Petroleum Associates, Inc., prepared for the U.S. Geological Survey, Reston, VA, October 1980.

[3] McCaffrey, B.J., "Some Measurements of the Radiative Power Output of Diffusion Flames", Paper No. WSS/CI 81-15, Western State Section/Combustion Institute Meeting, Pullman, Washington, April 1981.

[4] Markstein, G.H., "Scaling of Radiative Characteristics of Turbulent Diffusion Flames", 16th Symposium (Int.) on Combustion, The Combustion Institute, p. 1407 (1976).

[5] Brzustowski, T.A., Gollahalli, S.R., Gupta, M.P., Kaptein, M. and Sullivan, H.F., "Radiant Heating from Flares", American Society of Mechanical Engineers, New York, N.Y., Paper No. 75HT4 (1975).

[6] Gupta, M.P., "Experimental Investigation of the Radiation from Turbulent Hydrocarbon Diffusion Flames", M.S. Thesis University of Waterloo, March 1976.

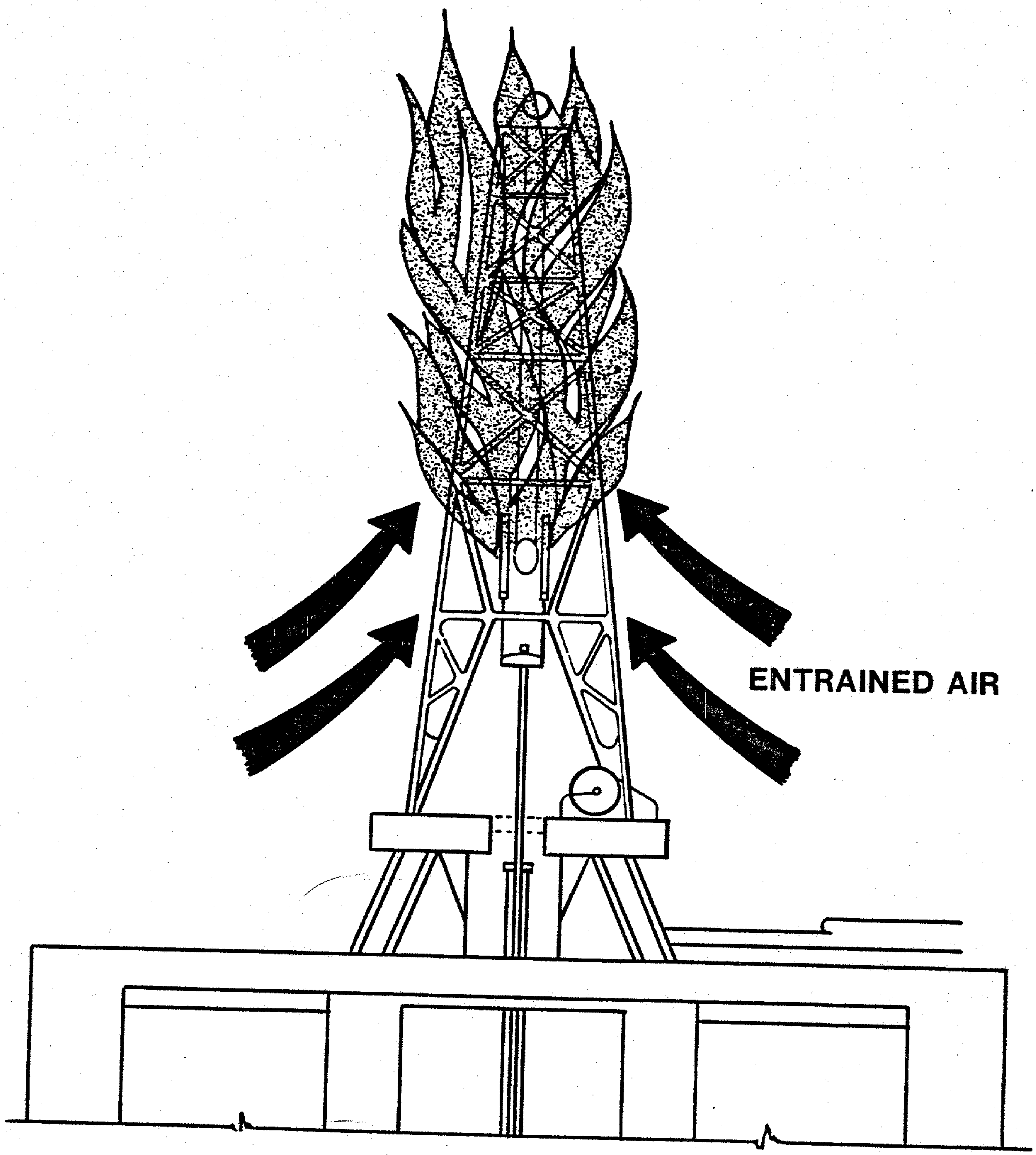


Figure 1 Blowout fire through drill pipe

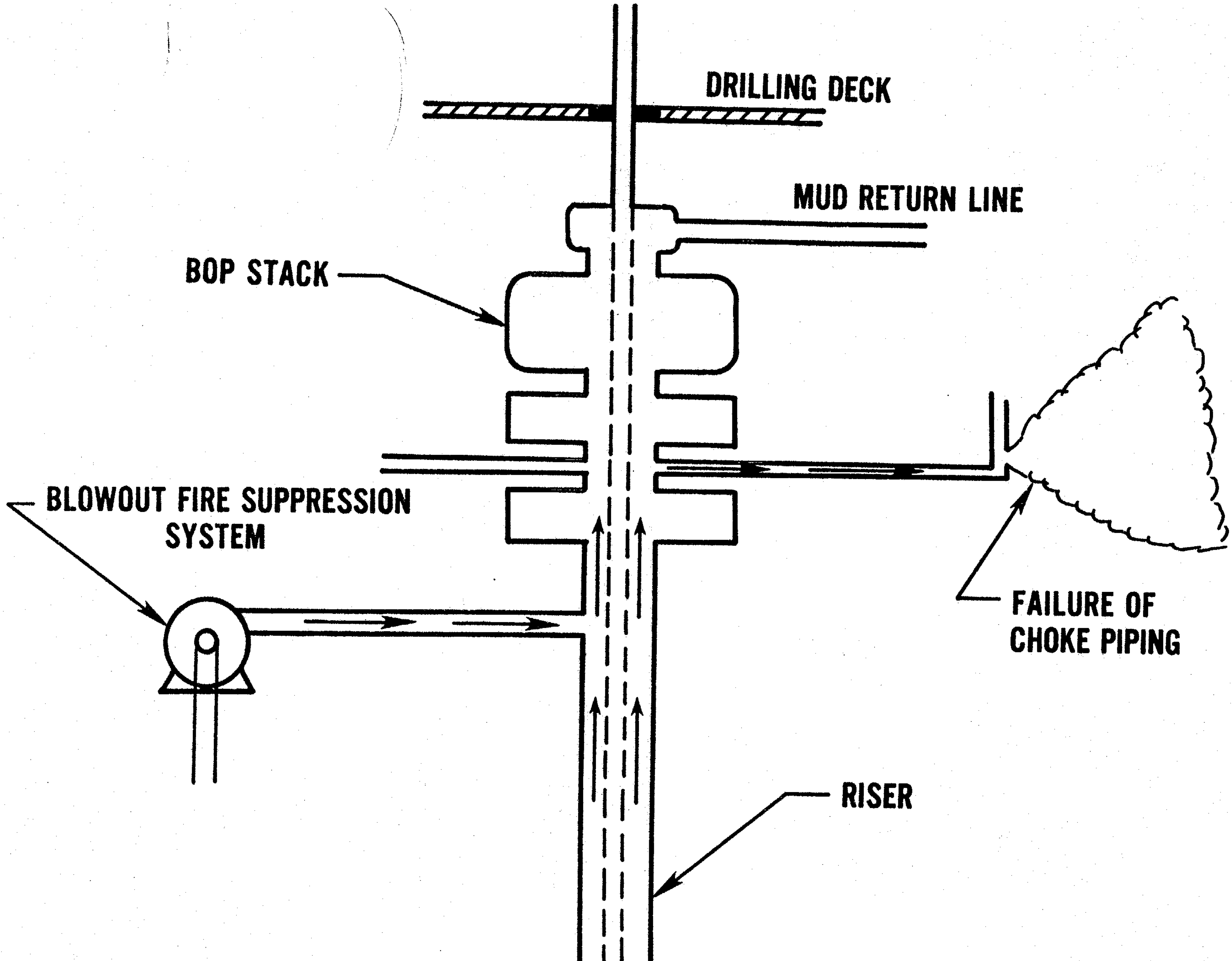


Figure 2. Conceptual Fire Suppression Injection System

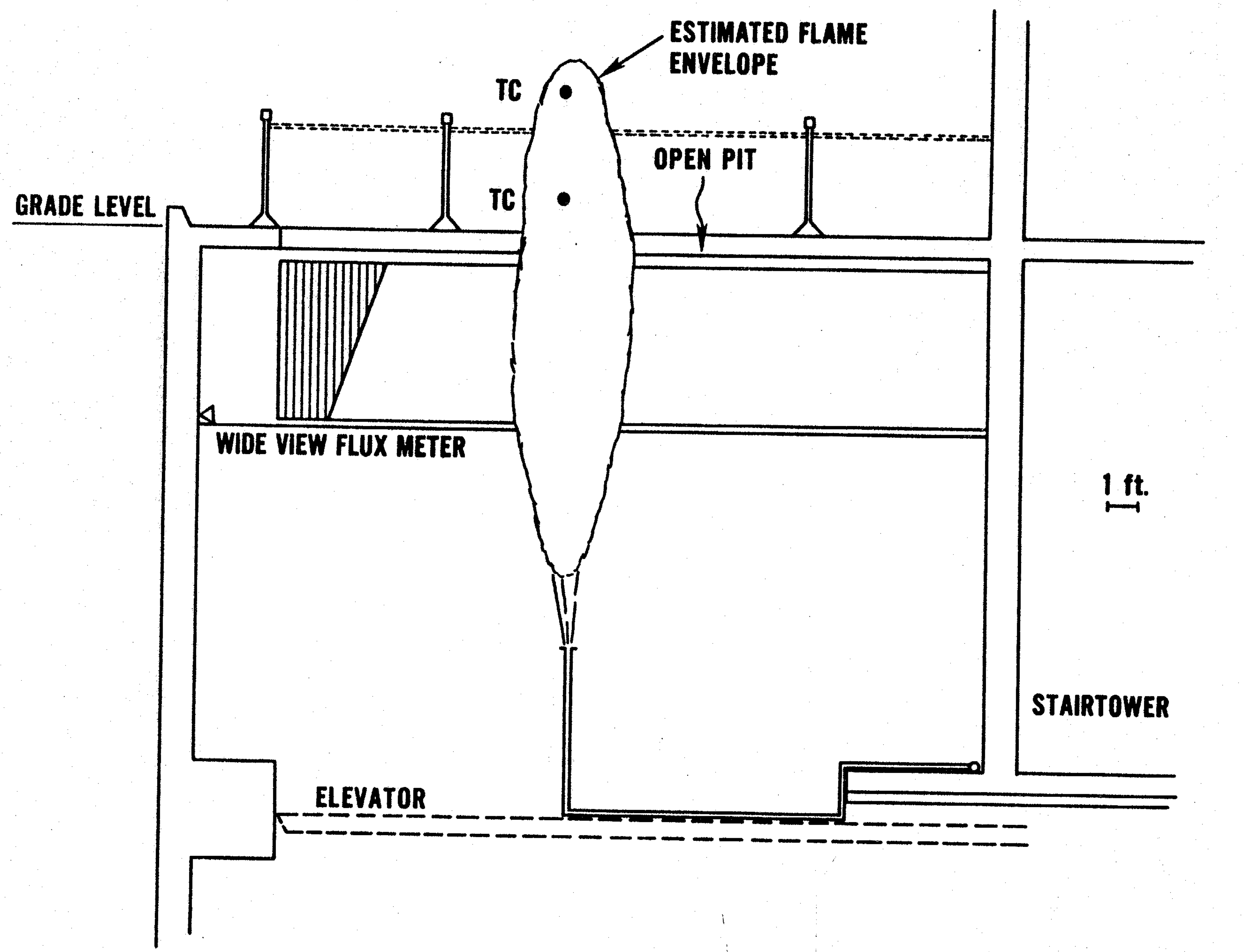


Figure 3. Blowout Suppression System Reduced Scale Test Facility

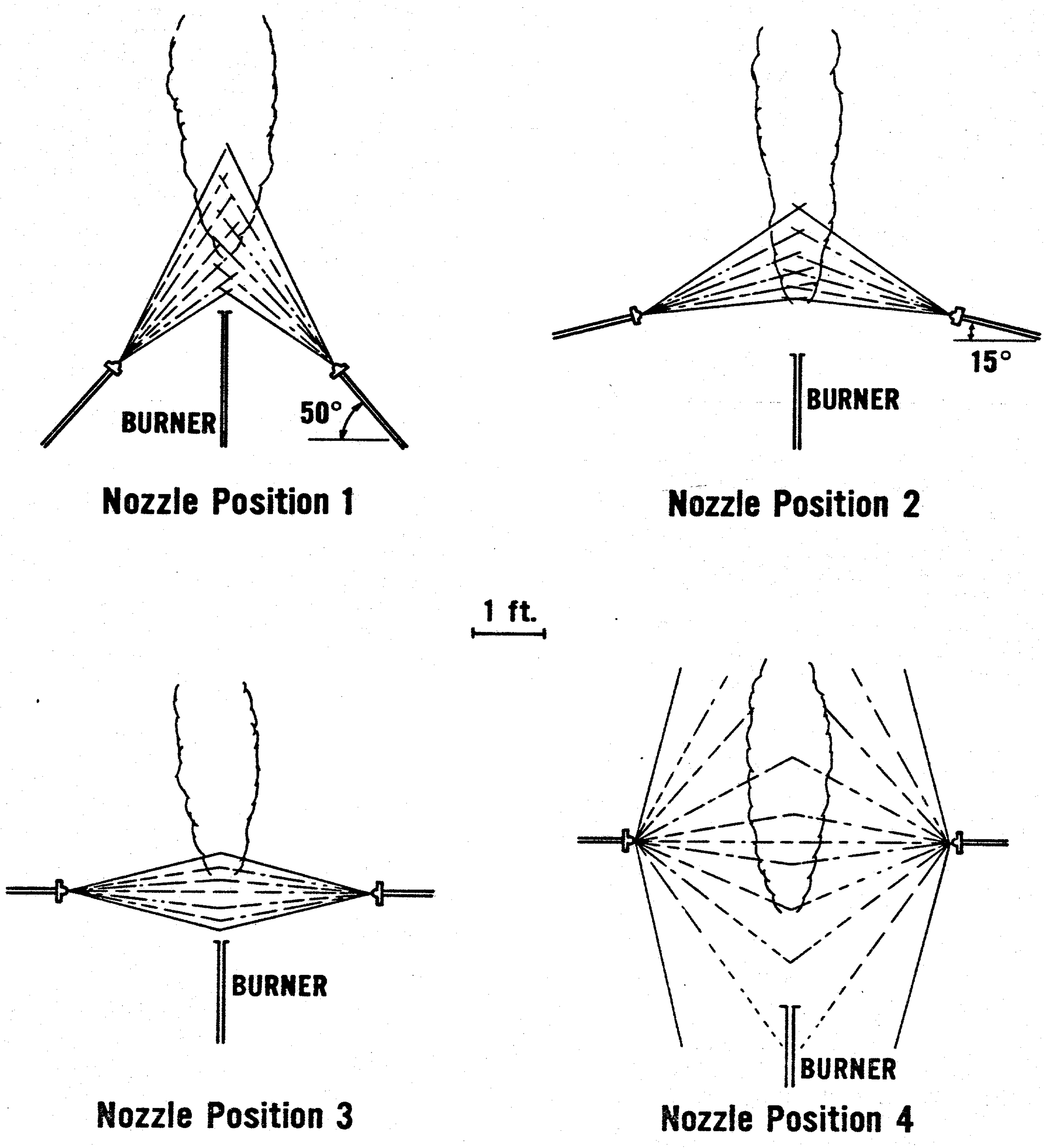
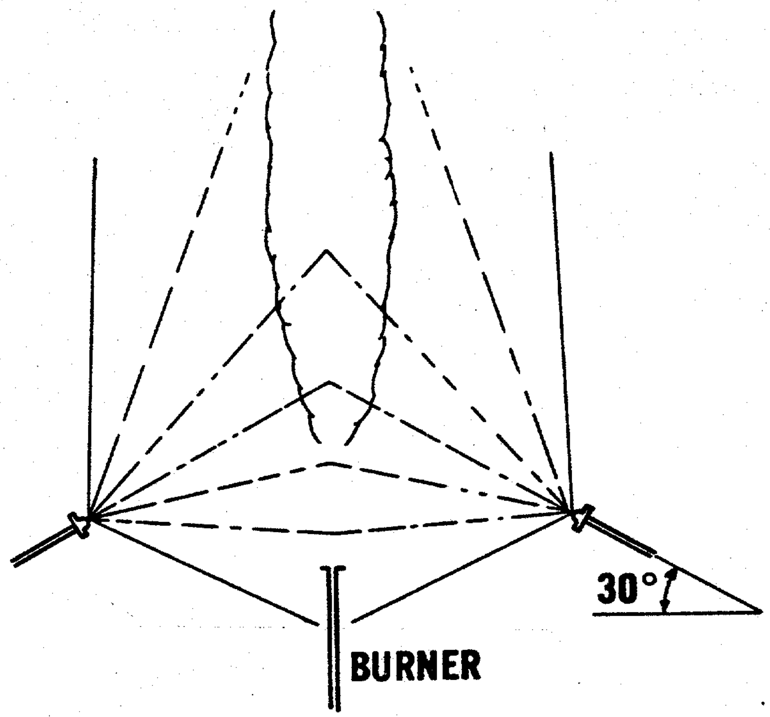
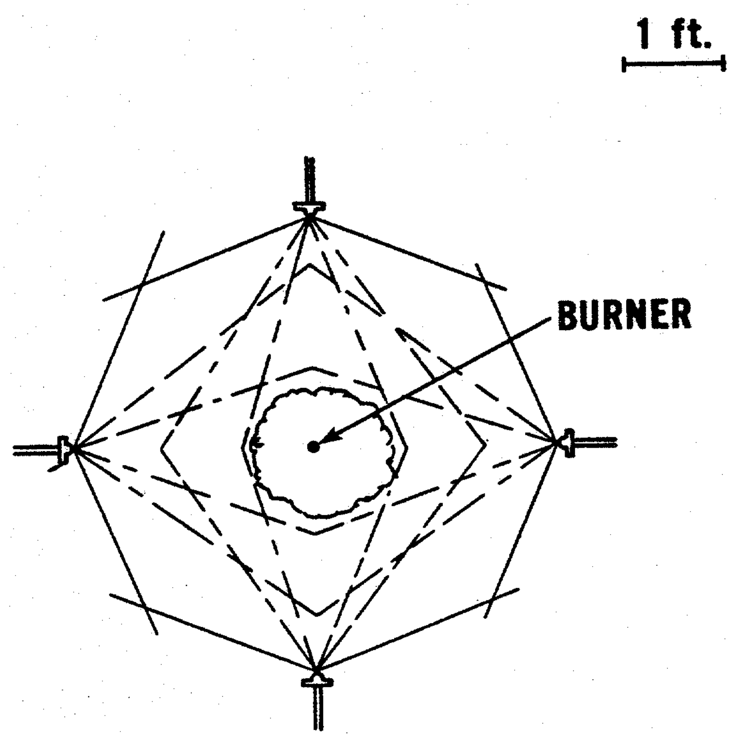


Figure 4. Exterior Water Spray Tests Nozzle Positions



Nozzle Position 5



Nozzle Position 6 (plan view)
Same as 5 with two additional nozzles

Figure 5. Exterior Water Spray Tests Nozzle Positions

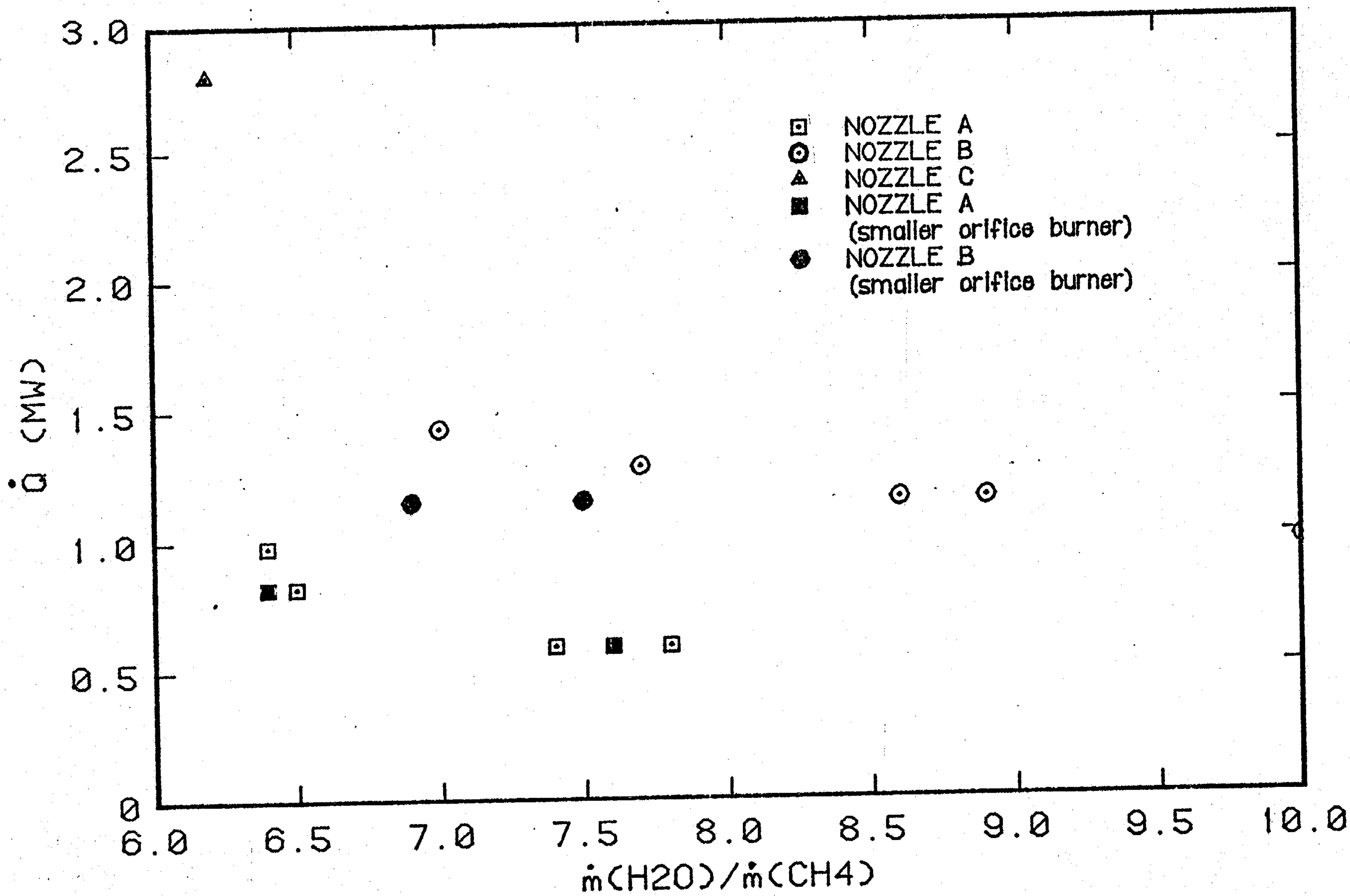


Figure 6. Exterior Water Spray Tests - Nozzle Position 1
Mass Flow Ratios Where Extinguishment Was Achieved

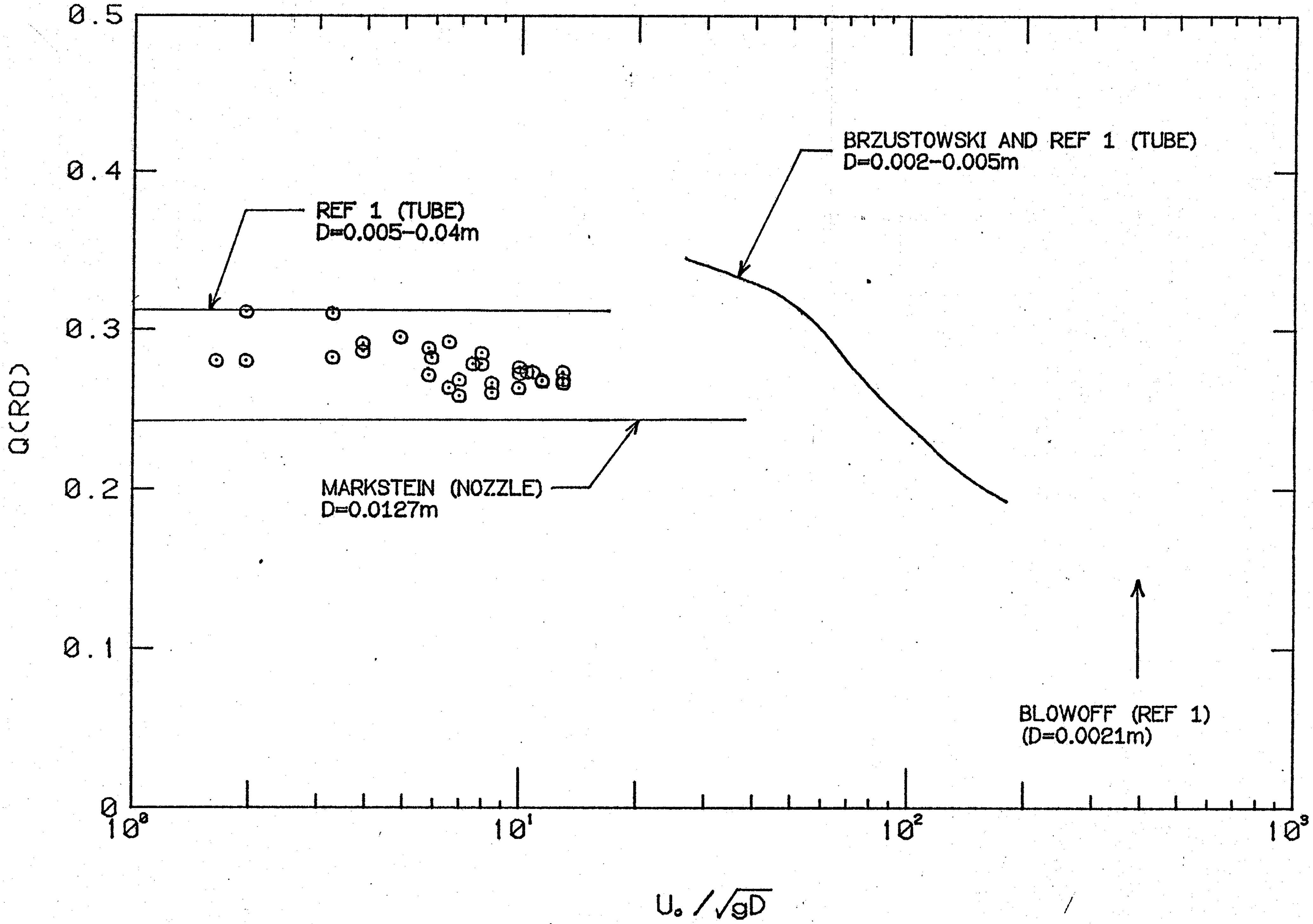


Figure 7. Radiative Fraction Plotted against Froude Number

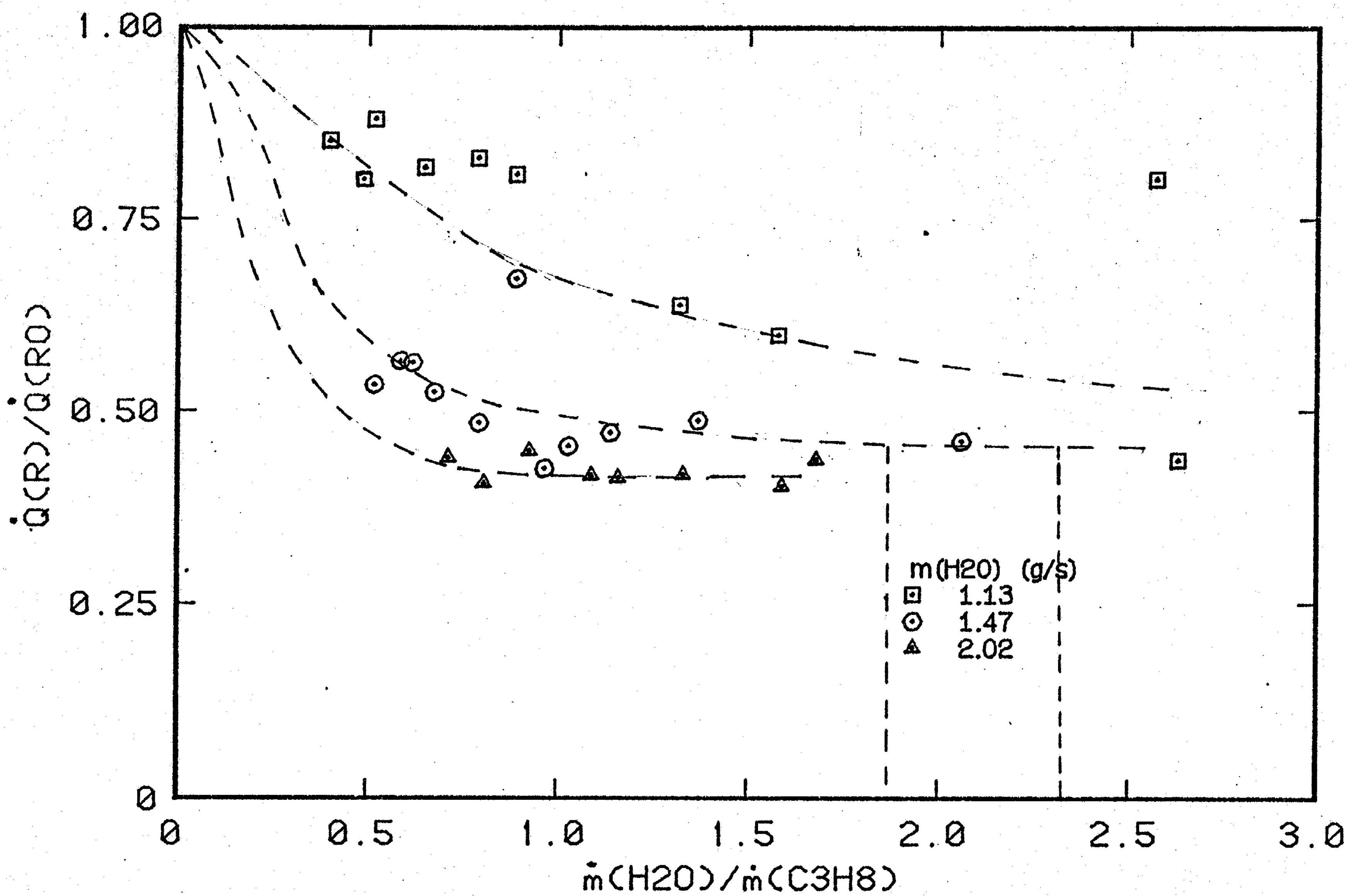


Figure 8. Water Injection Tests - Radiation Measured with Varying Mass Flow Ratios (Water to Gas)

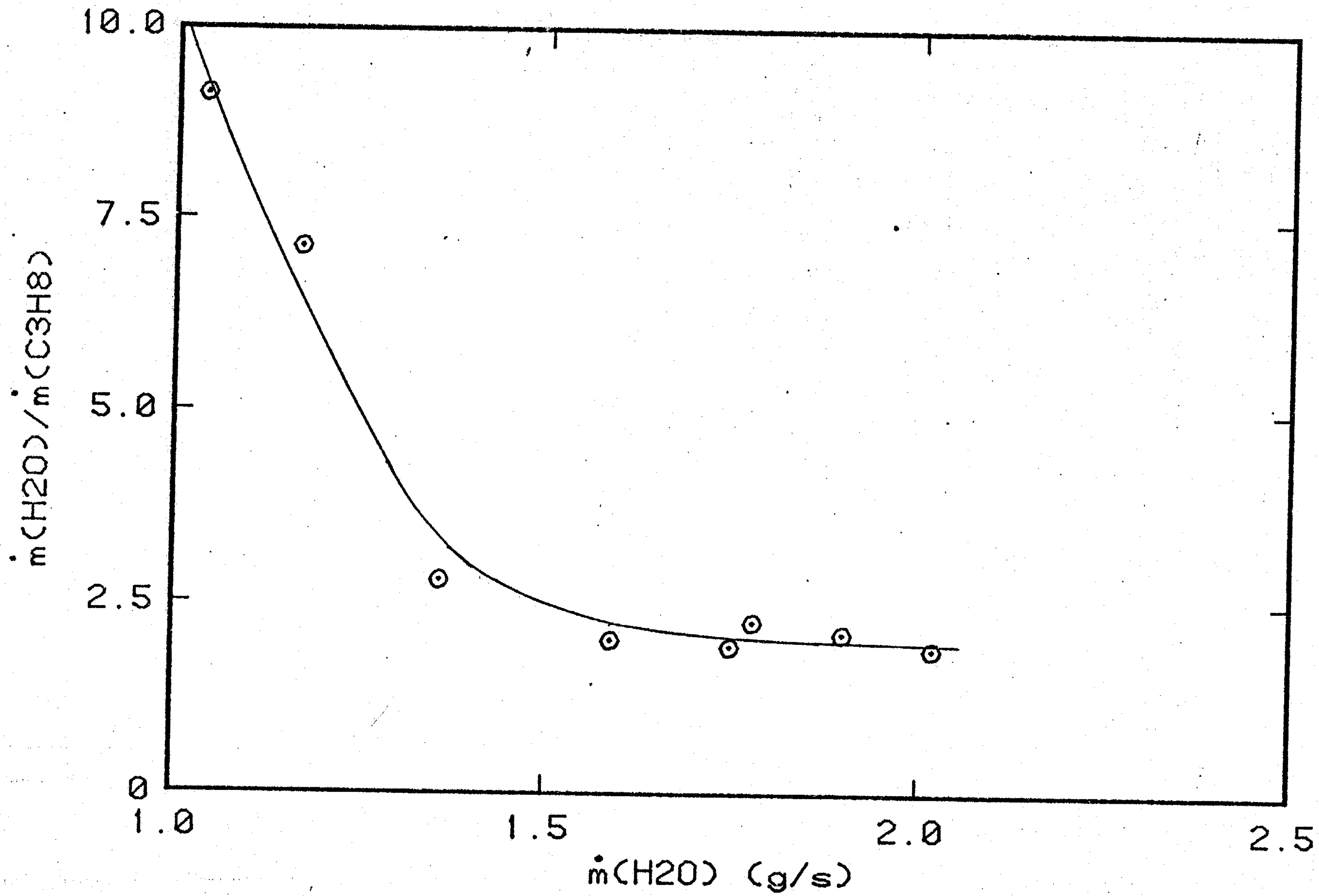


Figure 9. Mass Flow of Water to Mass Flow Ratios of Water to Gas where Extinguishment was Achieved